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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventors: Steven Martin HUDSON et al.	)
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Serial No.: 10/032,468	) Group Art Unit: 2661
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Filed: January 2, 2002	)
	)
For: Data Transmission In Pipeline Systems	)
	)
	)

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Assistant Commissioner for Patents
Washington, DC 20231

Sir:

CLAIM FOR PRIORITIES

Under the provisions of Section 119 of 35 U.S.C., applicants hereby claim the benefit of the filing dates of United Kingdom Patent Application Nos. 9915968.3 filed July 7, 1999; 9924027.7, filed October 11, 1999; and 0100107.2, filed January 3, 2001 for the above identified United States Patent Application.

In support of applicants' claim for priority, filed herewith is one certified copy of each of the above.

Respectfully submitted,

FINNEGAN, HENDERSON, FARABOW,
GARRETT & DUNNER, L.L.P.

Dated: April 10, 2002

By: ______________________
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The Patent Office

Cardiff Road
Newport
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1. Your reference — TJF/DC/31050

2. Patent application number *(The Patent Office will fill in this part)* — **9915968.3**

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

   Flight Refuelling Ltd.,
   Brook Road
   Wimborne
   Dorset
   BH21 2BJ

   Patents ADP number *(if you know it)* — 451625001

   If the applicant is a corporate body, give the country/state of its incorporation — United Kingdom

4. Title of the invention — Data Transmission Systems, Methods of Data Transmission, Signal Receiving Apparatus and Methods of Receiving Signals all for use in Pipeline Systems.

5. Name of your agent *(if you have one)* — fJ Cleveland

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

   40-43 Chancery Lane
   London WC2A 1JQ

   Patents ADP number *(if you know it)* — 07368855001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
   a) any applicant named in part 3 is not an inventor, or
   b) there is an inventor who is not named as an applicant, or
   c) any named applicant is a corporate body.
   See note (d))

   Yes

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Claim(s)	-
Abstract	-
Drawing(s)	4 + 4

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

fJ Cleveland
Signature fJCleveland
Date 7 July 1999

12. Name and daytime telephone number of person to contact in the United Kingdom T J Faulkner 0171 405 5875

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Data transmission systems, methods of data transmission, signal receiving apparatus and methods of receiving signals all for use in pipeline systems

This invention relates to data transmission systems, methods of data transmission, signal receiving apparatus and methods of receiving signals all for use in pipeline systems, in particular wells.

It is useful to be able to take measurements when drilling for oil and gas and during the operation of producing wells. However, it is difficult to transmit data from downhole locations to the surface and the difficulty increases with depth. At present there is a requirement for data transmission from 3000 metres or more below the surface.

Of the signalling techniques currently available those which make use of the metallic structure of the well itself are particularly preferred as they remove the need to install separate wirelines. Most non-wireline systems make use of the production string and casing as a single conducting channel and use earth as the return path. Some attempts have been made to use the casing and string as separate conduction paths but

this is fraught with problems because of the difficulties in isolating the string from the casing throughout its length and in particular at the wellhead because of the loads involved. Other methods include "mud-pulsing" which is not only difficult to implement and expensive but also gives a poor data rate.

Whichever system is used, the range is limited because of the inherent losses involved and the need to keep currents at reasonable levels. Further, to the applicant's knowledge no practical non-wireline systems are currently available for signalling from locations on the string within the casing. The communication system described in the applicant's earlier application EP-A-0,646,304, for example, works in open hole conditions and can transmit a signal along a cased section. However it is generally accepted that such a system cannot be used in practice to transmit from a position within a cased section.

It is an object of the present invention to provide communications systems which alleviate at least some of the problems associated with the prior art.

According to a first aspect of the present invention there is provided a data transmission system in which metallic structure of a pipeline system is used as a signal channel and earth is used as return comprising means for forming a current loop path having first and second conducting portions electrically connected to one another at spaced locations, the metallic structure comprising at least one of the conducting portions, and a local unit having transmitting means for applying a signal to one of the conducting portions whereby in use current flows around said loop generating a potential difference between earth and the metallic structure in the region of the loop and causing a signal to be propagated along the metallic structure away from the loop, wherein the means for forming the current loop path is arranged to ensure that the spaced locations are separated by at least a minimum distance selected to give desired transmission characteristics.

According to a second aspect of the present invention there is provided a method of data transmission in which metallic structure of a pipeline system is used as a signal channel and earth is used as return comprising the steps of:

forming a current loop path having first and second conducting portions electrically connected to one another at spaced locations, the metallic structure comprising at least one of the conducting portions; applying a signal to one of the conducting portions to cause a current to flow around said loop to generate a potential difference between earth and the metallic structure in the region of the loop and cause a signal to be propagated along the metallic structure away from the loop; and ensuring that the spaced locations are separated by at least a minimum distance selected to give desired transmission characteristics.

Typically the pipeline system comprises a well having a production string and surrounding casing.

The above arrangement has the advantage that a signal which will be detectable can be injected onto the metallic structure in practical situations using realistic current levels even when signalling along a production string from a position in which the string is located within a casing. Away from the region of the current loop path, the metallic structure as whole may be treated as a single conduction channel.

The minimum distance can be chosen to suit the circumstances such that an acceptable level of signal is detectable at the desired location remote from the local unit, for example at the well head. A typical selected minimum distance may be 100 metres. It is preferred that the selected minimum distance is small relative to the overall length of the structure/well.

Preferably one of the conducting portions comprises a portion of a production string. The transmitting means may be arranged to apply signals to the production string.

In some embodiments one conducting portion comprises a portion of a production string and the other conducting portion comprises a surrounding portion of casing. In such embodiments the means for forming a current loop path may comprise insulating spacer means for keeping the string spaced from the surrounding casing for the selected minimum distance. An insulating coating may be provided on the string and/or casing over the portion corresponding to the selected minimum distance. The spaced connections between the first and second conducting portions to complete the current loop path may comprise glancing

contacts between the string and casing beyond the selected region. It will be appreciated that the costs involved in improving isolation between the string and casing over the selected minimum distance will be significantly lower than those involved in trying to isolate the string and casing along their whole length.

In other embodiments one conducting portion comprises a portion of a pipeline or flowline and the other conducting portion comprises at least one electrically conductive elongate member connecting at least two pigs disposed within the pipeline or flowline. In such embodiments the spaced connections to complete the current loop path may be provided at the pigs. The local unit may be provided at one of the pigs. Preferably the transmitting means is arranged to apply signals to the elongate member.

The local unit may comprise sensor means for measuring conditions in the region of the unit. The local unit may comprise receiving means for receiving incoming signals transmitted along the metallic structure or otherwise. The local unit may be arranged to act as a relay station. It will be appreciated that the relay

station may be disposed on a cased section of production string and thus be used to improve the range of the data transmission system.

Preferably the transmitting means applies signals substantially at the midpoint of the respective conducting portion. This tends to equalise the signal propagation characteristics away from the local unit in both directions along the metallic structure and is particularly suitable if the local unit is to function as a bi-directional relay station. On the other hand, if it is desired to increase the signal transmission in one direction, the transmitting means may be arranged to apply signals at a point towards one end, preferably the opposite end, of the respective conducting portion.

The transmitting means and/or the receiving means may comprise an isolation member disposed in series with the respective conducting portion. The transmitting means may comprise a signal generating means connected across the isolation member. The receiving means may comprise a signal measuring means, for example voltage measuring means, connected across the isolation member. Where the respective conducting portion

comprises the production string the isolation member may be an isolation joint disposed in the string. The transmitting means and/or the receiving means may comprise inductive coupling means disposed around the respective conducting portion. The current loop path may act as a single turn winding of a transformer. The inductive coupling means may comprise a coil wound on a generally toroidal core which encircles the respective conducting portion.

According to a third aspect of the present invention there is provided signal receiving apparatus for use with a data transmission system in which metallic structure of a pipeline system is used as a signal channel and earth is used as return, comprising a local unit having receiving means, means for providing electrical contact between the local unit and at least two spaced locations on a portion of the metallic structure and means for ensuring that the two spaced locations are separated by at least a minimum distance selected to give desired reception characteristics.

According to a fourth aspect of the present invention there is provided a method for receiving a signal from the metallic structure of a pipeline system which is

used as a signal channel in a data transmission system with earth as return, comprising the steps of providing a local unit having receiving means; providing electrical contact between the local unit and at least two spaced locations on a portion of the metallic structure; and ensuring that the spaced locations are separated by at least a minimum distance selected such to give desired reception characteristics.

When a signal is transmitted along the metallic structure of a pipeline system the magnitude of the signal generally decreases as distance from the signal source is increased. This is mainly due to the gradual leakage to earth of the signal. Thus when a signal is travelling along the metallic structure there is a potential difference between any two longitudinally spaced points and it has been appreciated that providing a connection to two such points enables a signal to be extracted from the metallic structure. The minimum distance required depends on the signal level with respect to earth at the locations concerned and the sensitivity/noise performance of the receiving means.

The means for providing electrical contact at spaced locations may comprise a portion of the production string and insulating spacer means provided to keep said string portion spaced from the corresponding portion of surrounding casing. An isolation joint may be provided in the string in the region of the local unit and a signal measuring means connected across it. In this case, because the string is effectively isolated from the casing, all of the signal losses for that section of the metallic structure will be from the casing and there will be little potential drop along that portion of the string so that the potential difference between the spaced locations can be detected.

The means for providing electrical contact at spaced locations may comprise at least one electrically conductive elongate member connecting at least two pigs disposed within the production string.

According to a fifth aspect of the present invention there is provided signal receiving apparatus for use with a data transmission system in which metallic structure of a pipeline system is used as a signal channel, comprising a local unit having receiving

means which comprises an inductive coupling.

The signal channel may be split into two or more branches in the region of the local unit and the inductive coupling disposed around one of said branches.

Preferably the inductive coupling is disposed around a production string disposed within a casing. One branch may comprise the production string and another branch may comprise the casing.

The inductive coupling may comprise a toroid disposed around said one of the channels and/or a production string.

According to a further aspect of the present invention there is provided a data transmission system in which metallic structure of a well including a production string and casing is used as a signal channel and earth is used as return comprising a local unit having receiving and/or transmitting means coupled to the string for receiving signals from and/or transmitting signals along the signal channel and insulating spacer means arranged to ensure that the production string and casing are spaced from one another for at least a selected minimum distance in the region of the local unit, said minimum distance being selected to give

desired reception and/or transmission characteristics.

Many of the additional features described following the earlier aspects of the invention are equally appropriate for use in conjunction with said further aspect of the invention.

According to yet another aspect of the present invention there is provided apparatus for use with a metallic structure in carrying out any one of the above aspects of the invention.

Embodiments of the present invention will now be described by way of example only with reference to the accompanying drawings in which:

Figure 1 schematically shows a subsea well including a data transmission system which comprises a first embodiment of the invention;

Figure 2 schematically shows a portion of the well shown in Figure 1 at which a relay station is disposed;

Figure 3 shows a simplified equivalent circuit of a typical length of production string and casing of the well shown in Figure 1;

Figure 4 shows a simplified equivalent circuit of the portion of the well shown in Figure 2 during reception

of a signal;

Figure 5 shows a simplified equivalent circuit of the portion of the well shown in Figure 2 during transmission of a signal;

Figure 6 shows an alternative coupling method; and

Figure 7 is a schematic view of part of a second embodiment of the invention.

Figures 1 and 2 schematically show a subsea well including a data transmission system. The well comprises a production string 1 for extracting product from a formation F. The production string 1 joins a tree 2 at the mudline and is surrounded by casing 3 between the tree 2 and the formation F. The string 1 and casing 3 form part of the metallic structure of the well. Although Figure 1 shows the string 1 as being disposed centrally within the casing 3, in practice the string 1 and casing 3 will make glancing contact with one another at numerous positions along their lengths. In general there is nothing to prevent such glancing contact and the string 1 will follow a sinuous, for example a helical, path within the casing 3.

The space between the string 1 and casing 3 is filled with brine (or alternatively another fluid which is

denser than water) to help reduce the pressure acting on the packing ring 4 provided between the casing 3 and string 1 as they enter the formation F. The presence of the brine introduces a further conduction path between the string 1 and the casing 3.

The effect of the glancing contacts and conduction through the brine mean that in general corresponding points of the string 1 and casing 3 will reach the same potential and the string 1 and casing 3 must be treated as a single conductor.

The well also comprises a number of data logging stations 5 provided on the string 1 at open well locations, that is within the formation. The data transmission system is arranged to allow data to be transmitted between the data logging stations 5 and the mudline or beyond by using the metallic structure of the well 1,3 as a signal channel. The distance between the data logging stations and the mudline may be in excess of 3000 metres. Data is received at and transmitted from the data logging stations 5 using established open well techniques, for example those described in the applicant's earlier application EP-A-0,646,304. Whilst these techniques work in the open

well and can transmit a signal along the cased section they cannot be used in practice to transmit from a position within the cased section. Only if the length of the cased section is not too great can signals be received directly at and sent directly from the mudline using the techniques described in the above mentioned application; range and data rate being essentially determined by signal to noise ratio.

In the present embodiment however, the strength of the signal and/or range of the system is improved by providing a relay station 6 partway along the cased portion of the production string 1. Referring particularly to Figure 2, the relay station 6 comprises transceiver means including an isolation joint 7 provided in the production string, signal generating means 8a used during transmission and signal measuring means 8b used during reception. Both the signal generating means and the signal measuring means are connected across the isolation joint 7. A plurality of insulating annular spacers 9 are provided around the production string 1 over a distance of the order of 100 metres in the region of the isolation joint 7. The distance over which the spacers 9 are provided is chosen such that signals can be

effectively received and transmitted. The actual distance will depend on a number of factors relating to the components of the transmission system and the well itself.

The spacers 9 are of a half shell type which are bolted together around the string 1. An insulating layer 9a is provided between each spacer and the string 1. In Figure 2, a side view of one of the spacers 9 is shown and the remainder of the spacers 9 are shown in cross-section. The spacers 9 are arranged and positioned such that at each spacer 9 the string 1 is held towards the centre of the casing 3 and such that the string 1 will not contact with the casing 3 at any position between adjacent spacers 9. Beyond the last spacer 9 at each end of the plurality of spacers 9, the string 1 makes glancing contact 10 with the casing 3 as shown in Figure 2. The distance between each last spacer 9 and the respective glancing contact 10 will be random but its lower limit will be determined by characteristics of the well and spacers 9. Thus the spacers 9 ensure that there is no contact between the string 1 and casing 3 for at least a selected minimum distance.

In general terms the transmission and receiving characteristics of the system improve as the spacing

between the glancing contacts 10 is increased. However, there is a trade off against the cost involved in lengthening the minimum distance. In general the actual spacing between the glancing contacts 10 will be greater than the minimum distance but this simply serves to improve the system.

The portions of the string 1 and casing 3 between the glancing contacts 10 are hereinafter referred to as the isolated portion of the string 1a and the corresponding portion of the casing 3a.

Figure 3 shows an equivalent (lumped parameter) circuit for a typical length of the production string 1 and casing 3. The string 1 and casing 3 are respectively represented by series of resistors R_s and R_c. The leakage paths between the string 1 and casing 3 are represented by a series of resistors R_{g+b} and the leakage paths between the casing 3 and remote earth E are represented by resistors R_e and capacitors C_e. If a signal is applied to the string 1 or casing 3 the strength of the signal will decrease with distance away from the source due to the losses through the leakage paths to remote earth E. Further, as mentioned above the potential of the string 1 and casing 3 will tend to equalise.

Figure 4 shows a simplified equivalent circuit

for the portions of the production string 1a and casing 3a in the region of the relay station 6 during reception of a signal. Except those 10 at either end of the portions 1a, 3a, the leakage paths due to glancing contacts have been removed. Thus the resistors R_{g+b} are replaced by resistors R_b of much higher value representing the leakage through brine alone. The resistance through the brine in the region of the relay station 6 is so large compared with that provided by the glancing contacts 10 at the ends of the isolated portion of string 1a that the effect of the brine can essentially be ignored.

During reception of a signal, because there is no current path through the string portion 1a due to the isolation joint 7 and because the string portion 1a is effectively isolated from the corresponding casing portion 3a, all of the signal losses for that section of the metallic structure will be from the casing 3a. In this circumstance there will be little potential drop along the two halves of the isolated string portion 1a which essentially provide a direct contact with the glancing contacts 10 at the end of the portions 1a,3a. This means that the potential difference between two longitudinally spaced locations on the casing can be detected and hence a signal

extracted from the metallic structure. The fact that all of the signal is forced along the casing 3 in the region of the relay station 6 can serve to increase the potential difference between the two spaced locations on the casing 3.

Figure 5 shows a simplified equivalent circuit for the portions of the production string 1a and casing 3a in the region of the relay station 6 during transmission. As above the leakage paths due to glancing contacts have been removed except those 10 at either end of the portions 1a, 3a. Thus the resistors R_{g+b} are replaced by resistors R_b of much higher value representing the leakage through brine alone. The resistance through the brine in the region relay station 6 is so large compared with that provided by the glancing contacts 10 at the ends of the isolated portion of string 1a that the effect of the brine can be ignored. Thus during transmission a current loop path can be considered to exist consisting of the isolated portion of the string 1a, the corresponding portion of the casing 3a and the glancing connection points 10. The two ends of this loop are of course also connected to the remainder of the string 1 and casing 3. The signal generating means 8a causes a current I to flow around

the loop path. This flow of current I causes a potential difference to be set up between the glancing contacts 10 at opposite ends of the isolated portion of string 1a. This potential difference will be I x sumRc, where sumRc equals the total resistance of the casing between the glancing contacts 10.

Assuming that the isolation joint 7 is provided at the centre of the isolated portion of the string 1a and the system settles in balance relative to earth, the magnitude of the potential difference between metallic structure and earth at each end of the isolated portion 1a will be (I x sumRc)/2. Because a potential difference exists between the positions of the glancing contacts 10 and earth, a signal will tend to travel along the string 1 and casing 3 in each direction away from the relay station 6.

Desired data, for example that received from a data logging station, can be transmitted along the string 1 and casing 3 away from the relay station by encoding a suitable signal onto the string 1 by means of the mechanism described above.

Appropriate receiving means at the mudline or at another relay station (not shown) are used to detect

the signal applied to the string 1 and casing 3 and extract the desired data. The receiving means may make use of an inductive coupling or be arranged to measure signals with respect to a separate earth reference.

Thus the range of the signal transmission system can be dramatically increased by providing a suitable number of relay stations within the casing 3. The relay stations are bi-directional so that the transmission range when transmitting signals down into the well as well as out of the well is increased.

With the isolation joint located centrally within the isolated portion 1a, the signals in each direction away from the relay station 6 will have substantially equal strength. However, if the isolation joint 7 is disposed towards one end of the isolated portion 1a, the potential difference generated at the other end of the isolated portion 1a will tend to be greater than (I x sumRc)/2. Thus if it is desired to increase the strength of the signal in one direction the isolation joint 7 may be disposed accordingly.

In an alternative the isolated portion of the production string 1a is provided with an insulating coating to further reduce conduction between the

isolated portion 1a and the corresponding portion of the casing 3a.

Figure 6 shows a coil 201 provided on a toroidal core 202 disposed around the production string portion 1a for use in an alternative method of applying a signal to and/or tapping a signal from the production string 1. In this case inductive coupling is relied on and no isolation joint is used. During transmission the coil 201 is used to induce a current in the string 1 and the current loop path described above acts as a single turn transformer winding. During reception, a signal on the production string 1 induces a corresponding current in the coil 201 which can be detected. This method of reception does not rely on there being an isolated portion 1a of production string. This coupling method gives an advantage that it is possible to optimise impedance matching by appropriately choosing the turns ratio.

Figure 7 shows a further embodiment of the invention suitable for use in a well of the type described above which comprises two pigs 301 connected by an electrically conductive strop 302 and disposed within the production string 1 which may or may not be cased. A first of the pigs 301 comprises a local station 303

having an isolation member 7 provided in series with the strop 302 and signal generating means 8a and signal measuring means 8b connected across the isolation member 7. Each of the pigs 301 has a contact 304 for contacting with an internal surface of the string 1.

Signals may be transmitted and received in this embodiment in substantially the same way as described above in relation to the first embodiment. During transmission the strop 302, a portion of the string 1a and the contacts 304 form a current loop path. When current is caused to flow around the loop by the signal generating means 8a a potential difference between the string 1 and earth can be generated at each contact 304 allowing a signal to be transmitted. During reception of a signal, the strop 302 and contacts 304 allow the potential difference between two longitudinally spaced points on the string 1 to be measured so that a signal can be extracted from the string 1.

In this embodiment signals may be sent to and from the first pig 301. In particular, signals may be sent from the pig 301 which allow the location of the pig 301 to be determined and/or which represent a quantity, such as wall thickness, measured by the pig

301.

In implementing this embodiment it is desirable to minimise the impedance of the conductive strop 302 and the contacts 304 between the pigs 301 and the production string 1. Wire brushes (not shown) provided around the pigs 301 for cleaning purposes may be used as the contacts 304.

One possible mechanism for determining the location of the pig 301 would be to arrange trigger means at spaced locations along a pipeline which cause the pig 301 to send an appropriate signal. Another method would be to determine the time difference of arrival of the signal at each end of the pipeline.

It will be appreciated that this system may be used whether the pigs 301 are within a cased or uncased section of string. Further the system may be used in other pipeline systems besides wells.

In alternatives more than two pigs may be used. Three pigs connected by two conductive members may be used and the local unit disposed at the central pig. This can facilitate equalisation of the transmission characteristics in both directions away from the local unit.

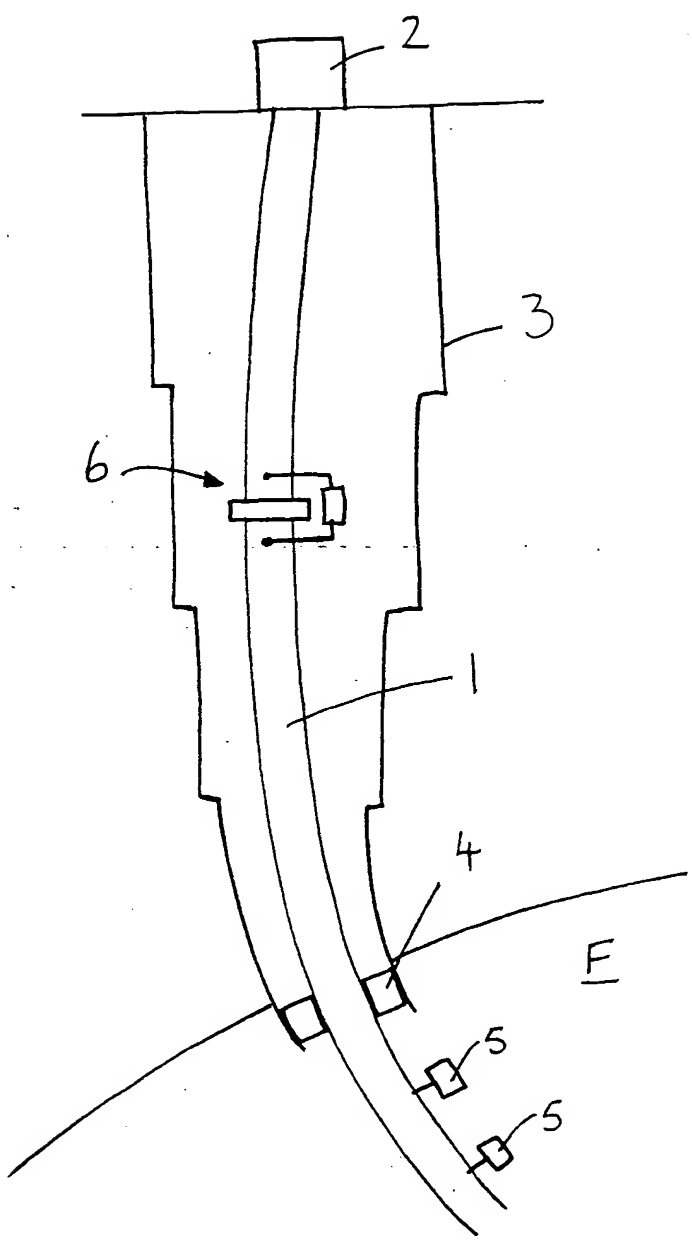

FIG. 1

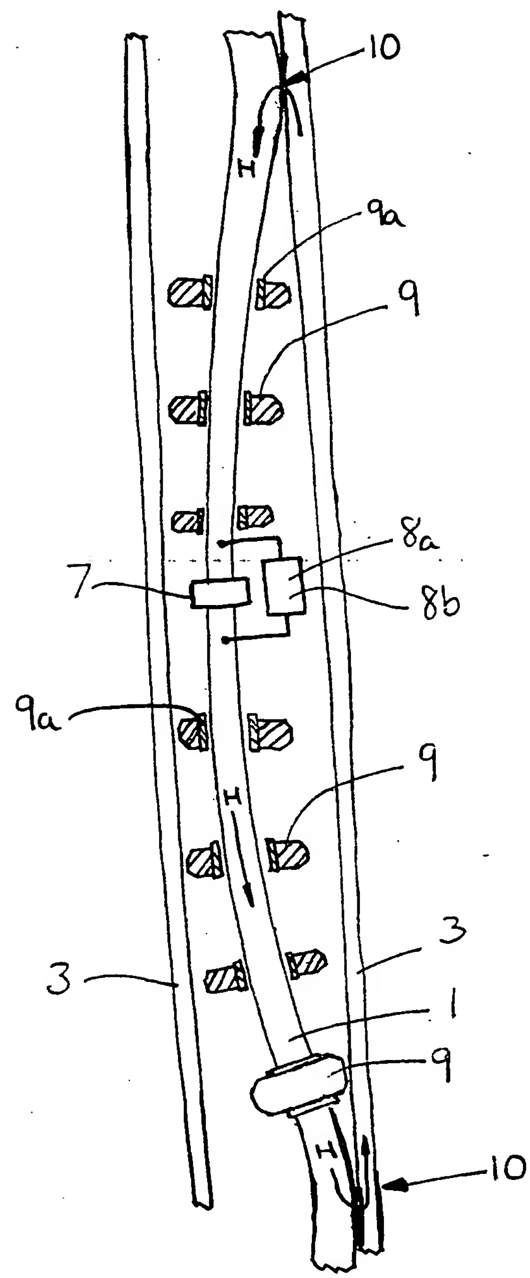

FIG. 2

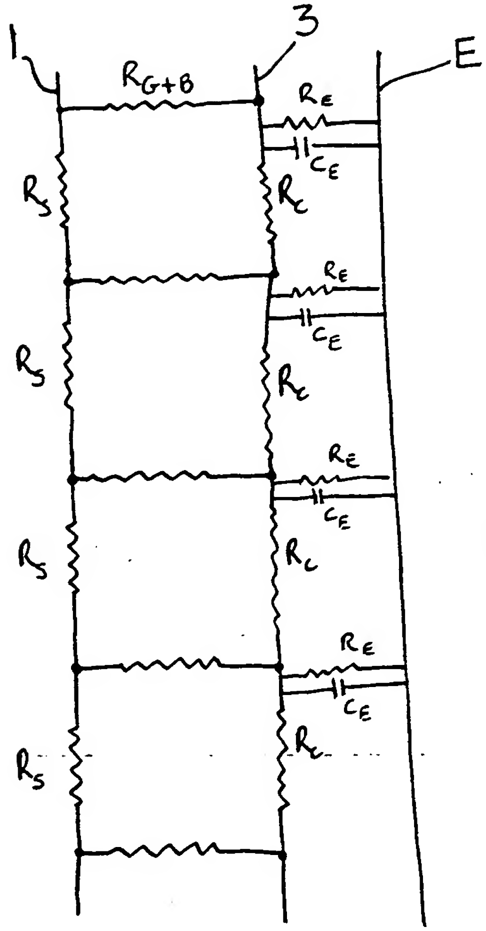

FIG. 3

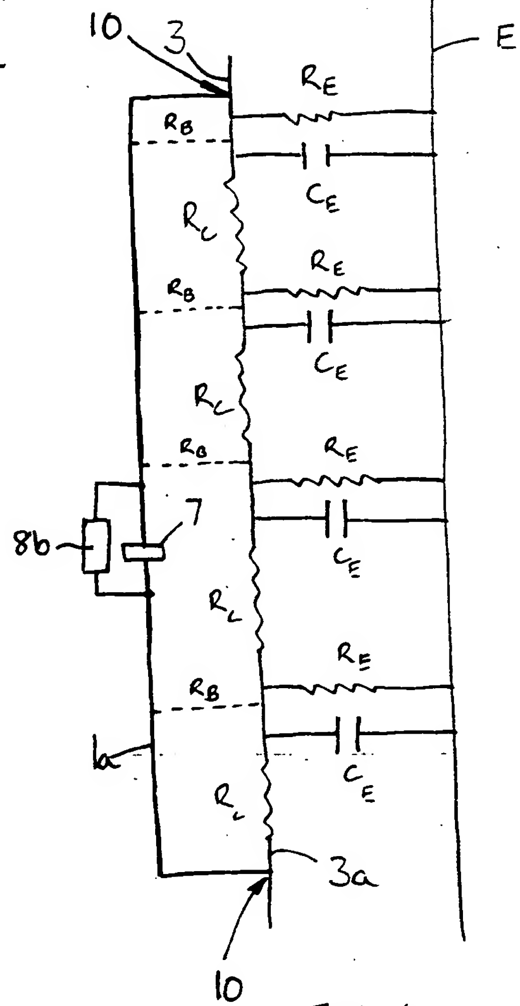

FIG. 4

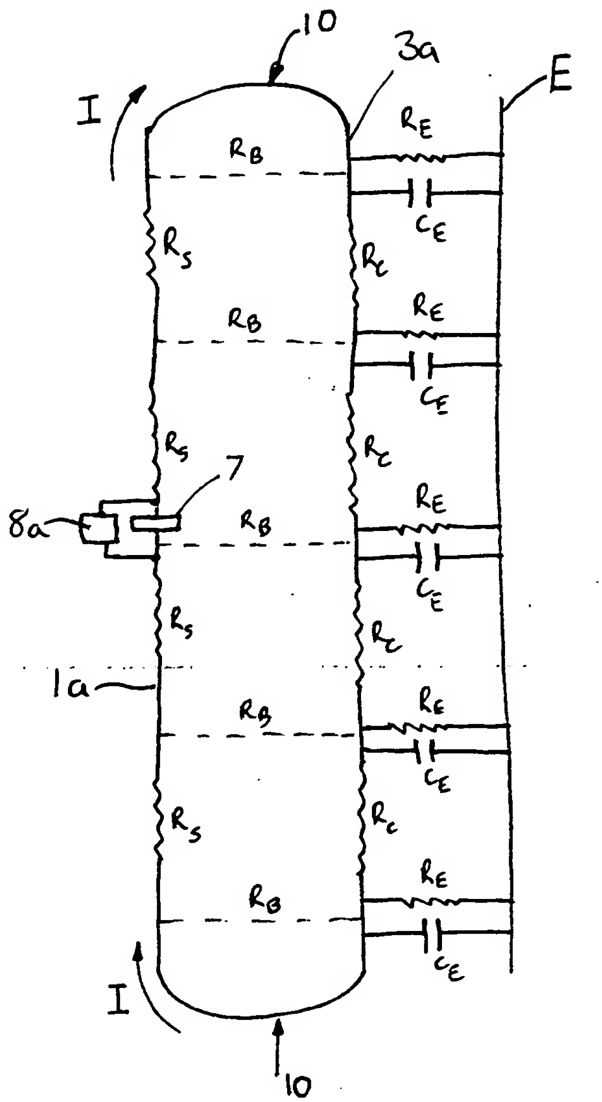

FIG. 5

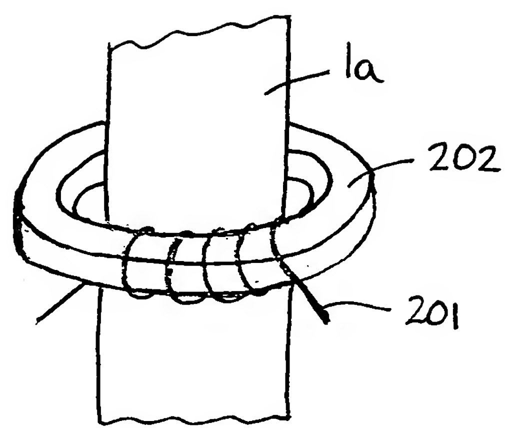

FIG. 6

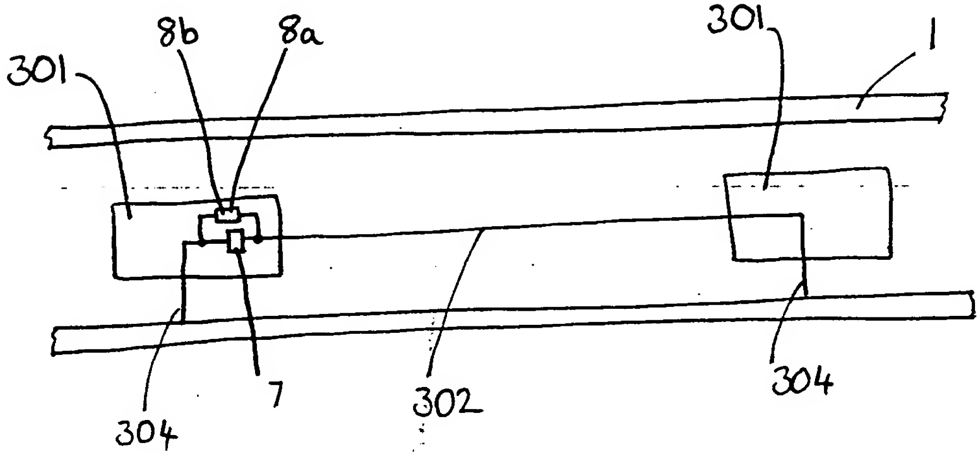

FIG. 7